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Short communication

A practical method for determining electrode positions on the head

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Summary When multi-channel EP recordings are used for source localization, the electrode positions have to be determined with respect to a common reference frame. In this paper a method is described for determining the electrode positions on the head. Since it is difficult to fix electrodes accurately at a priori chosen positions, it is better to measure these positions afterwards. For this we have developed a practical method. The method also finds the best fitting sphere for the electrode positions, which is useful when a multi-sphere volume conductor is used in the inverse algorithm.

Key words: Multi-channel EP recording; source localization; electrode positions, method

Multi-channel evoked potentials (EPs) are commonly used to locate the equivalent sources which generate these brain potentials (e.g., Randall and Aunon 1982; Maier et al. 1987). Source localization techniques are based on a mathematical model which describes the head as a volume conductor and the sources as current dipoles. Much attention has been given to systematic errors in the estimated sources, due to modeling errors (e.g., Arthur and Geselowitz 1970; Stok 1987; Peters and De Munck 1990). Simulation studies show that source position errors caused by conductivity errors are in the order of centimeters (Peters and De Munck 1990), whereas source position errors caused by not taking into account the source extension are much smaller (De Munck et al. 1988).

When a spherical volume conductor is used to describe the head, it is obvious that an error in the position of the best-fitting sphere will have a large effect on the results of the source localization procedure. However, little attention has been given to the coordinate frame in which the equivalent sources are defined. The required accuracy of the electrode positions also seems to have been overlooked; an exception is the recent publication of Gevins et al. (1989) where the electrode positions were measured with a 3-D digitizer. In many studies the electrode coordinates are defined first, the electrodes then being fixed as accurately as possible. For instance, Ary et al. (1981) proposed a mechanical method based on the construction of a plastic helmet which precisely fits the subject's head. In this study we fixed the electrodes more or less arbitrarily in the region of interest and measured the positions afterwards with a pair of compasses.

Since the spherical model is the only model capable of finding inverse solutions of MEG, the estimation of the best fitting sphere is of prime importance for MEG. Several studies have been performed to find this sphere (e.g., Romani and Leoni 1985; Weinberg et al. 1986; Lütkenhöner et al. 1990). For EEG the determination of the best fitting sphere and the recording sites can be solved simultaneously, as is proposed in this paper.

In the following section a reference frame is defined and a method is described to determine the electrode positions with respect to this frame. In the section 'Simulations', some simulations are presented to demonstrate the accuracy of the method.

Method

First, a coordinate system is defined with respect to the head (Fig. 1). The origin O is at the middle of the line segment connecting the external auditory mati (earholes). The (positive) y-axis runs from the origin to the right external auditory matus and the (positive) x-axis runs from O in the direction of the inion. If this axis intersects the inion, then an easy third reference is obtained. For simplicity of expression we assume that this third reference point is indeed the

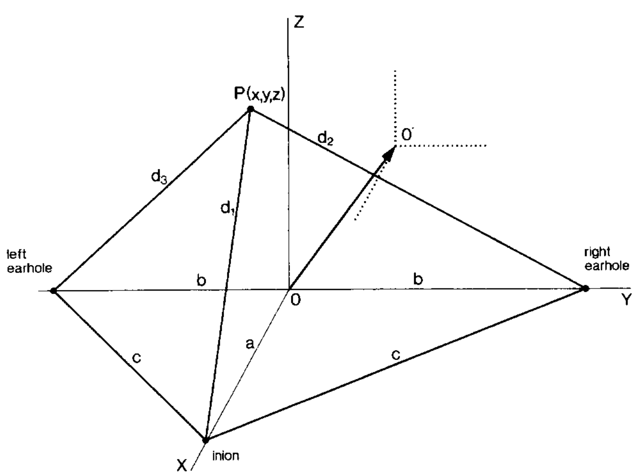

Fig. 1. Determination of the electrodes with respect to the 'best-fitting sphere.' First, the distances 2b and c are measured, and then for each electrode the distances d_1, d_2 and d_3 are measured. The center of the sphere which fits the electrode positions best is located at O′.

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inion. This is, however, not essential for the method, since only 3 reference points are required to define the frame. The (positive) z-axis starts at the origin and is oriented normally to the x-y plane. When the ear-ear distance (2b) and the inion-ear distance (c) are known, the location of electrode P_i is uniquely defined by the distances d_1, d_2 and d_3 (Fig. 1). By positioning the legs of a pair of compasses at the electrode location and at a reference point, the chords d_j can be measured directly.

The following system of equations expresses these distances in the cartesian coordinates of the electrode:

$$\begin{cases} d_1 = \sqrt{(x-a)^2 + y^2 + z^2} \\ d_2 = \sqrt{x^2 + (y-b)^2 + z^2} \\ d_3 = \sqrt{x^2 + (y+b)^2 + z^2} \end{cases} \quad (1)$$

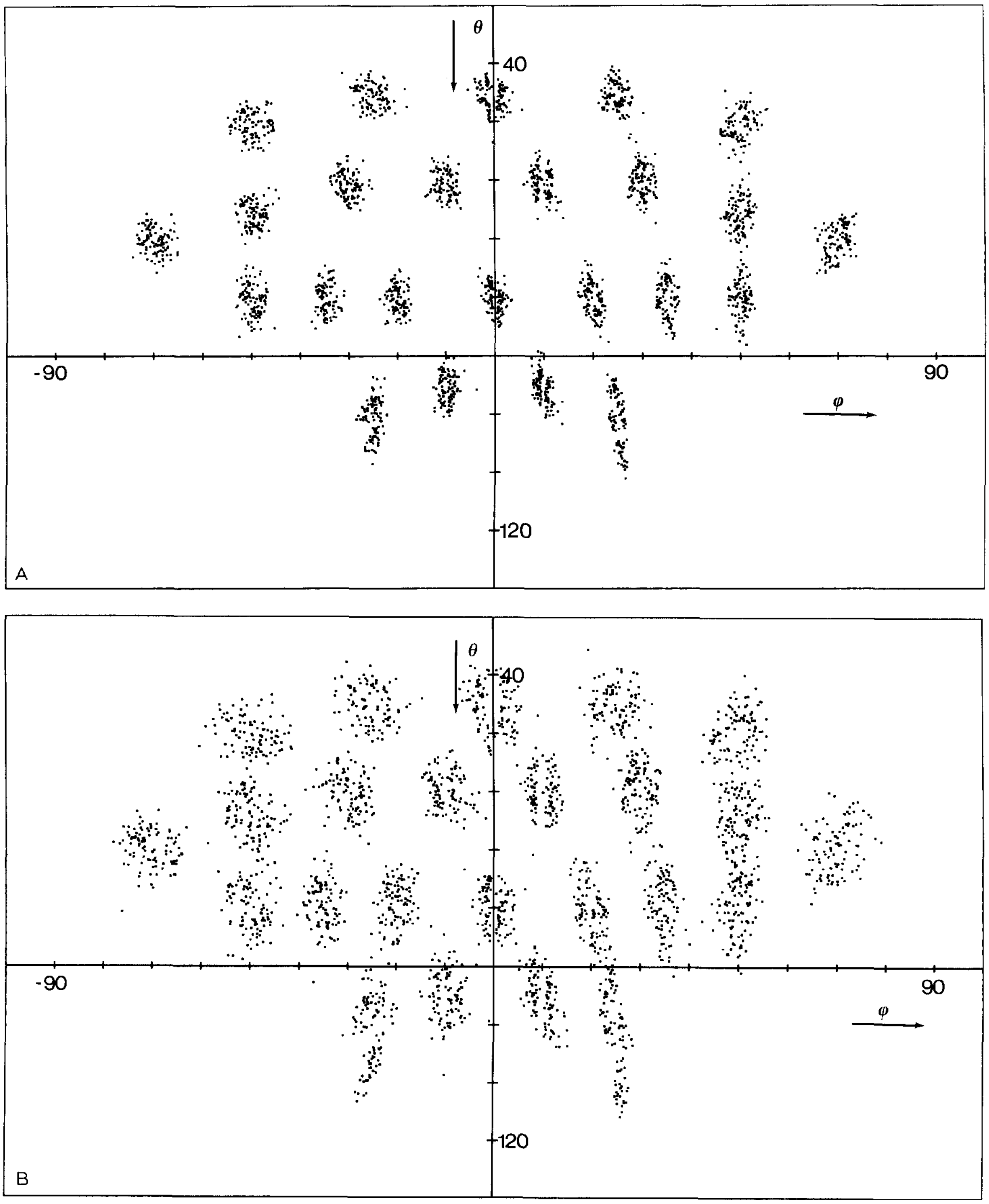

Fig. 2. The electrode positions in spherical coordinates. Each dot of a group represents the result of a measurement error simulation. In the top panel the standard deviation of the electrode measurement was 2.5 mm and in the bottom panel it was 4 mm.

The cartesian coordinates of P_i can be found by solving this system:

$$\begin{cases} x = \left(2a^2 - 2b^2 - 2d_1^2 + d_2^2 + d_3^2\right)/4a \\ y = \left(d_3^2 - d_2^2\right)/4b \\ z = \pm\sqrt{d_2^2 - x^2 - (y-b)^2} \end{cases} \quad (2)$$

Here, the plus sign must be applied if the electrode is above the x-y plane, and the minus sign if it is below this plane.

Next, we consider the problem of finding the best fitting sphere $S(\vec{x}_0, R)$, with center $\vec{x}_0$ and radius R. If $\vec{x}_i' = \vec{x}_i - \vec{x}_0$ is the vector pointing from the center of S to the i-th electrode then $|\vec{x}_i' - (R/r_i')\vec{x}_i'|$ is the distance between S and $\vec{x}_i$, in which $r_i' = |\vec{x}_i - \vec{x}_0|$. The best fitting sphere minimizes the sum of the squares of all these distances. We have

$$H = \min_{\vec{x}_0, R} \sum_{i=1}^{I} \left| \vec{x}_i' - \frac{R}{r_i'}\vec{x}_i' \right|^2 = \min_{\vec{x}_0, R} \sum_{i=1}^{I} \left(|\vec{x}_i - \vec{x}_0| - R \right)^2 \quad (3)$$

The minimum of H can be found easily with the Simplex algorithm (e.g., Caceci and Chacheris 1984), which appears to be quite insensitive to the choice of starting values.

In summary the method proposed consists of the following steps: (1) measure a and b; (2) measure d_1, d_2 and d_3 for each electrode; (3) calculate $\vec{x}$ for each electrode using Eqn. (2); (4) minimize H in Eqn. (3) using the Simplex method. This yields $\vec{x}_0$ and R; (5) calculate the electrode positions with respect to the best fitting sphere using $\vec{x}_i' = \vec{x}_i - \vec{x}_0$; (6) find the dipole position $\vec{y}'$ with respect the best fitting sphere; (7) calculate the dipole position with respect to the inion-ear system using $\vec{y} = \vec{y}' + \vec{x}_0$.

Simulations

The precision of the method depends on the accuracy of the measurements of d_1, d_2 and d_3. To investigate the effects of measurement errors on the positions of the electrodes and on the result of the source localization, some simulations were performed. A spherical head was assumed, with a radius of 100 mm. The center of the sphere had an x coordinate of 10 mm, an y coordinate of 0 mm, and a z coordinate of 40 mm. These numerical values correspond to the average values we found in practice. On the head were 24 electrodes with known positions. Eqn. (1) was used to calculate the exact distances d_1, d_2 and d_3. Then, these distances were disturbed by adding gaussian noise of zero mean and known standard deviation. The disturbed distances were used as input of the Simplex algorithm, and the results were compared to the real positions of the electrodes.

Fig. 2 shows a scatter diagram of the electrodes, for 2 different standard deviations of the measurements and for 100 simulations each. It appears that for a standard deviation of 2.5 mm the electrodes stay within a circular area with a radius of about 4°. For a standard deviation of 4 mm this radius amounts to 6°.

Although these results seem to indicate that the distances d_i have to be measured very precisely, they do not say anything about the accuracy of the source localization procedure. To simulate this effect we calculated the potential caused by two time varying dipoles at known electrodes. In these simulations the same dipole parameters were used as in Peters and De Munck (1990). The electrode positions were disturbed, and a dipole localization procedure (De Munck 1990) was applied on the potentials and the disturbed electrode locations. The resulting equivalent dipoles were compared to the real dipoles. It was concluded that for a standard deviation of 2.5 mm the dipole position error was approximately 4 mm. For a standard deviation of 4 mm these errors were about 10 mm.

Discussion

The method we propose for determining the positions of the electrodes requires a minimum number of distances to be measured. Since these measurements can be performed easily with a standard deviation of less than 2.5 mm, the dipole position estimation is affected only slightly by measurement errors. When a spherical volume conductor model is used to describe the head, the method automatically yields the position and radius of the best-fitting sphere. If the electrodes are restricted to an area which is too small to give a realistic equivalent sphere (e.g., when all electrodes are positioned near one of the temples), then additional points on the skin should be included to improve the estimation of the best-fitting sphere parameters. The main advantage of the method is that it gives the dipoles with respect to a well-defined coordinate system, so that dipole parameters can be unambiguously related to cortical areas.

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